Solid Rocket Combustion Simulation Using the Hybrid Combustion Process

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Historically, test evaluation of new designs, materials, and processes for solid rocket motor nozzles and insulators at MSFC has been carried out using heavyweight, facility solid rocket motor test-beds. However, if the solid-propellant combustion environment and associated nozzle/insulation material response is simulated using a hybrid motor test-bed, significant cost savings and expanded test flexibility could be achieved. Ongoing testing in the East Test Area, under the Large Subscale Solid Rocket Combustion Simulator program, has led to the development of a family of solid rocket combustion simulators. Testing completed to date includes subscale solid rocket combustion simulators (11 and 24 inches in diameter) that have validated the use of the hybrid combustion process for solid rocket motor simulation.

Utilizing the combustion simulator design approach—which combines an inert solid-fuel grain with a liquid-oxygen injection system in an effort to simulate a solid rocket motor, while maintaining the safety and control attributes of a liquid system—provides a unique national asset not currently available with conventional rocket motor test-beds. The combustion simulator test-beds allow for rocket motor component overtesting, margin testing, and controlled test to failure. The Large Subscale Solid Rocket Combustion Simulator program, initiated by NASA in September 1993, is being performed by Lockheed Martin Astronautics, with Thiokol Space Operations and the Rocketdyne Division of Rockwell International functioning as major subcontractors.

The 11-inch motor was used to develop regression rate correlations for the DX fuel formulation, selected to simulate the solid rocket combustion environment. Twenty-four-inch motor testing completed to date has evaluated ballistic scale-up effects, multiport motor effects, fuel overcast capability, and the initiation of a control system to enable motor operation at a constant chamber pressure and mixture ratio.

Figure 61 illustrates the various components that make up the 24-inch combustion simulator system. Testing of the 24-inch-diameter combustion simulator system was completed in July 1995 at MSFC. A total of seven tests were conducted using the circular port configuration over a wide range of motor pressures and oxidizer flow rates. Stable combustion was observed on all tests, with nozzle throat erosion ranging from 3 to 8 mils per second. This performance compares favorably with the performance of a similar-sized solid rocket motor.

In conjunction with these tests, an innovative approach for the measurement of web thickness was demonstrated. Ultrasonic transducers were installed in steel housings welded to the motor case. The development of a pulse-echo thickness measurement technique provided for real-time measurement of web thickness during motor firing. The data obtained by the ultrasonic measurement technique agree closely with pre- and posttest web thickness measurements. This system will provide a real-time estimation of fuel flow rate for use in computing mixture ratio and subsequent mixture-ratio control.

Additional testing utilized a seven-port wagon-wheel grain configuration and

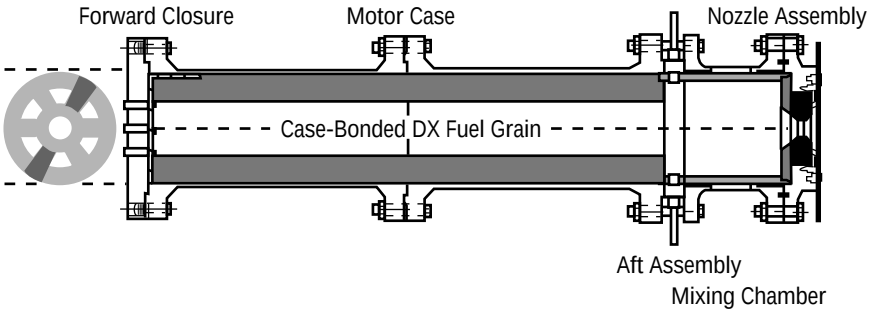

FIGURE 61.—24-inch solid rocket combustion simulator.

provided an increased understanding of the ballistic characteristics of DX fuel. Integration of a closed-loop control system—providing for real-time adjustment of an electrohydraulic valve and the corresponding adjustment in liquid-oxygen flow rate and resulting chamber pressure—was also initiated during this test series.

Figure 62 illustrates the chamber pressure profile from test L2494–090. The control system gain setting—initially set excessively high in order to respond quickly to chamber pressure deviations—resulted in an unstable control solution. However, a midtest reduction in gain provided for a stable control solution. Test L2494–090 demonstrated a significant advancement in hybrid motor control and chamber pressure (thrust) tailoring.

Testing to date on the Large Subscale Solid Rocket Combustion Simulator program has established the viability of the combustion simulator concept through testing with the 11- and 24-inch solid rocket simulators. A valuable data base has been compiled to allow for future evaluation of advanced solid rocket motor materials and processes. The overall system will provide invaluable advancement of solid propulsion.

Abel, T.M.; Boardman, T.A.; and Crawford, J.T. November 15–17, 1994. Rocket Nozzle Materials Testing Using a Solid Rocket Combustion Simulator. Joint Army, Navy, NASA, and Air Force Rocket Nozzle Technology Subcommittee Meeting, Seattle, Washington.

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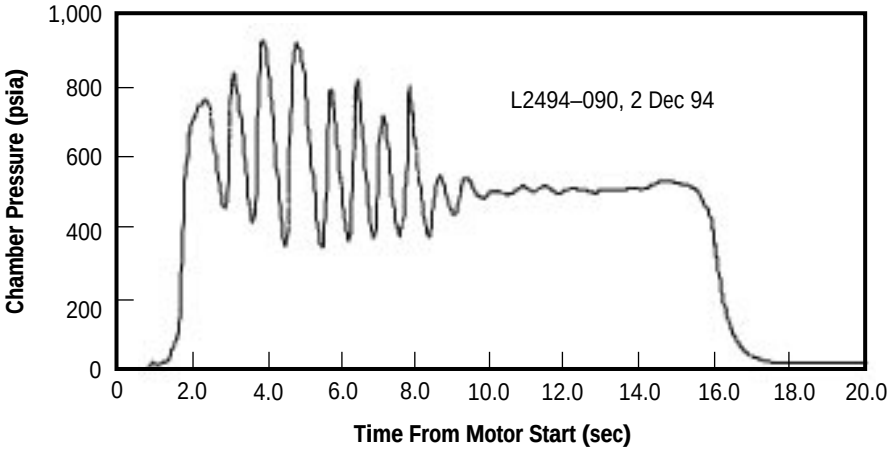

FIGURE 62.—Control system integration test.